Plywood Design Specification

Supplement No. 2

Design of Plywood Beams

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Foreword

This publication presents the recommended method for the design of glued plywood beams fabricated in accordance with FABRICATION OF PLYWOOD BEAMS. Working stresses and other design criteria are given in the PLYWOOD DESIGN SPECIFICATION, hereafter referred to as PDS. References are also made to the NATIONAL DESIGN SPECIFICATION FOR STRESS-GRADE LUMBER AND ITS FASTENINGS—National Forest Products Association, hereafter referred to as NDS.

This design method applies only to beams with glued joints. Design of mechanically fastened beams is covered in other publications. For further information, contact American Plywood Association, Technical Services Division.

This recommended design method is based on data developed by the U.S. Forest Products Laboratory, supplemented with tests by the American Plywood Association.

Technical Services Division
American Plywood Association

A Word on Components

Plywood-lumber components are major structural members which depend on the glued joints to integrate the separate pieces into an efficient unit capable of carrying high stresses. Materials in these components may be stressed to an appreciably higher level than in conventional construction.

Since improperly designed or fabricated components could constitute a hazard to life and property, it is absolutely essential that not only the design method offered here be followed but that adequate quality control be maintained during manufacture.

To be sure that such control has been carefully maintained you may wish to contact the Plywood Fabricator Service (PFS). A requirement that each unit bear the PFS "Quality-Inspected" trademark will assure you of adequate independent inspection and testing of production.

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Design of Glued Plywood Beams—PDS Supplement No.2*

1. General

1.1 Beam Behavior

In plywood beams, the lumber flanges carry most of the bending, and one or more plywood webs carry the shear. Joints between them transfer stresses from one to the other.

Vertical stiffeners set between flanges distribute concentrated loads and resist web buckling. Deflection resulting from shear is usually significant, and must be added to the bending deflection. Lateral restraint is often required to maintain stability. End joints in flange laminations and webs may require splicing.

1.2 Shape

Loads, spans, and allowable stresses, as well as desired appearance, determine the beam proportions. The depth and cross section may be varied along the length of the beam to fit design requirements, provided the resisting moments and shears at all sections are adequate.

2. Fabrication

2.1 Class of Construction

For design purposes, the distinctions between classes of construction are given in Sections 2.1.1 and 2.1.2. See FABRICATION OF GLUED PLYWOOD BEAMS for fabricating specifications required to produce these distinctions.

2.1.1 Class I Beams

Class I beams are intended as those with flanges of glued-laminated construction.

2.1.1.1 Class Ia Beams—Class Ia beams have no butt joints in either flange.

2.1.1.2 Class Ib Beams—Class Ib beams may have butt joints in either flange.

2.1.2 Class II Beams

Class II beams are intended as those with flanges of stress-grade lumber as defined by standard lumber grading rules.

2.2 Gluing Pressure Methods

2.2.1 Nail and Pressure Gluing

For Class I beams, lumber flanges of more than one lamination must be glued under positive mechanical pressure. Plywood may be glued to other plywood or to lumber under positive mechanical pressure, or with pressure applied by nails or staples.

2.2.2 Stresses for Glued Joints

Shear stresses for glued plywood joints may equal allowable values given in the PLYWOOD DESIGN SPECIFICATION, without regard to pressure method used.

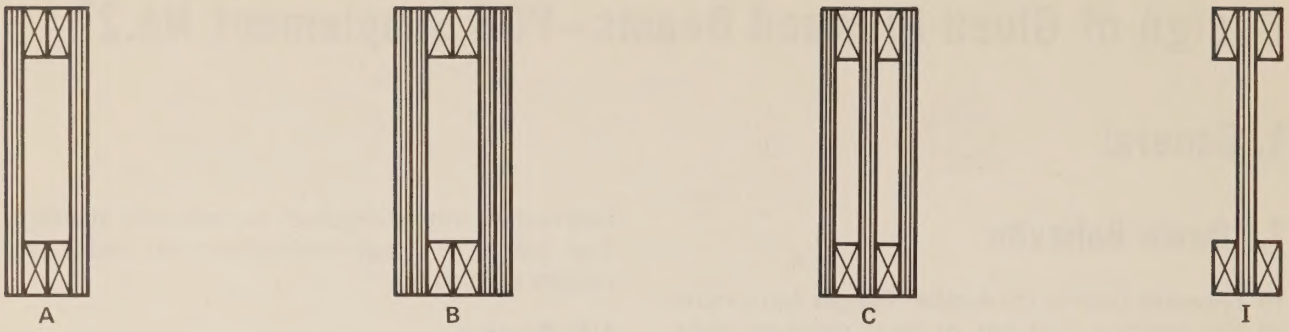
2.3 Slope of Grain in Flange Laminations

Standard grading rules contain restrictions on slope of grain. These restrictions, however, are based on the assumption that each piece is used full-length as a single-span beam, and greater grain slopes are therefore allowed in the end thirds of the piece. When such lumber is used for laminating flanges of box beams it must be regraded with reference to its location in the finished beam, unless lower stresses are to be used. Thus, a piece which will fall completely within a highly stressed area should have the most stringent restriction applied to its full length, while a piece which will fall entirely outside a highly stressed area would actually require only the least stringent requirement throughout its length.

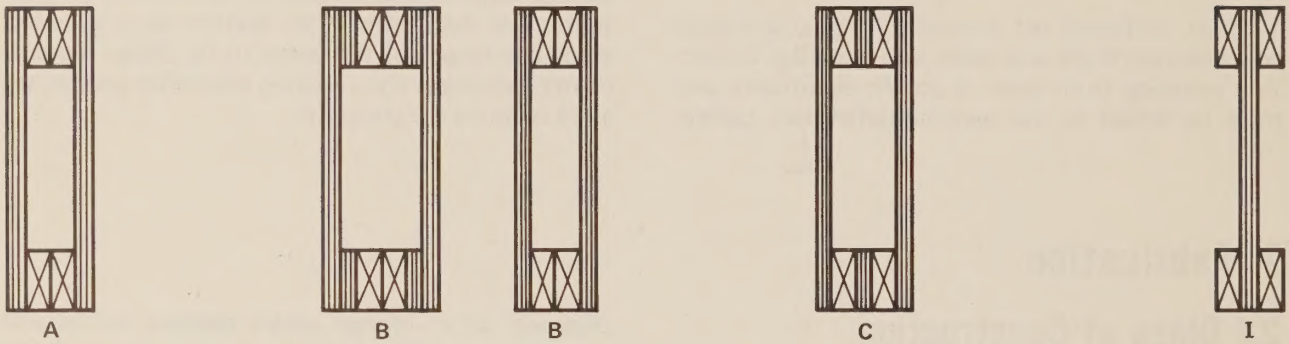
2.4 Design Depth

Beams should be designed for an actual depth slightly less than their nominal depth, to allow for resurfacing. Actual depth of beams under 24" deep is 3/8" less than nominal; for beams 24" and deeper, actual depth is 1/2" less than nominal.

*Previously Design Method No. BB-8D



TYPICAL SECTION IN OUTER PORTIONS



TYPICAL SECTION IN CENTER PORTION

FIGURE 2.5 Beam Types

2.5 Beam Types

Four types of beam cross sections are common, each being suited to certain uses and fabricating requirements. See Figure 2.5.

2.5.1 Type A

Type A beams are box beams having a uniform cross section throughout their length, with plywood webs on both sides of lumber top and bottom flanges. Webs may be nail-glued.

2.5.2 Type B

Type B beams are box beams similar to Type A, but having extra webs where needed for shear reinforcement. In uniformly loaded single-span beams, the extra webs are placed in the outer portions of the beam, but location for other conditions may be varied to suit the design requirements. The extra webs are attached directly to the primary webs, permitting the use of nail-gluing, and may be either outside or inside the primary webs. When they are inside, shims must be used alongside the flanges in the single-web portions of the beam to fill out the space occupied by the extra web in the other portions.

2.5.3 Type C

Type C beams are similar to Type B in having extra webs where required by shear, but since these extra webs are sandwiched between flange laminations, the beams require pressure-gluing for assembly. Type C beams have greater flange-web shear capacity than Type A or B beams. Shims are required in portions of the beam not having the center web(s).

2.5.4 Type I

I beams are similar to Type C, in requiring pressure-gluing, but because they have only a single web, they do not have as high a loading capacity nor as great torsional rigidity.

3. Design Considerations

3.1 Design Loads

The design live loads should not be less than required by the governing building regulation. Dead load is the actual weight of the member and the elements it supports. Allowance should be made for any temporary erection loads, or moving concentrated loads such as cranes.

3.2 Allowable Working Stresses

Working stresses are determined as described in PLYWOOD DESIGN SPECIFICATION Sections 5.4 and 5.5, with due regard for duration of loading.

Values for compression and tension parallel with the grain depend on species, grade, number of laminations, slope of scarf joints, and moisture condition. Values are given in the NDS and may be applied as outlined in PLYWOOD DESIGN SPECIFICATION Sections 5.5 and 5.7. Also, Appendix Section A5.5.3 of the PLYWOOD DESIGN SPECIFICATION gives values for laminated lumber of less than four laminations for certain species, when regraded for customary lumber grades.

For symmetrical sections the design should be based on the stress allowable in tension or compression, whichever is less. When butt joints occur in the tension flange, the design should be based on compression, or 0.8 times the tension stress, whichever is less.

3.2.1 Class I Beams

Allowable stresses for flanges of Class I beams should not exceed those for "Other Glued-Laminated Lumber", as given in the PLYWOOD DESIGN SPECIFICATION Section 5.5.3.2.

> Allowable stress level at any point in the flanges of Class Ib beams must be determined on the basis of the number of laminations continuous at that point. Any lamination with a butt joint within ten times the lamination thickness of the point under investigation is considered discontinuous.

3.2.2 Class II Beams

Allowable stresses for flanges of Class II beams should not exceed those for stress-grade lumber, as given in NDS Table 1. If laminations in the tension flange are not regraded for slope of grain, the allowable stress in tension parallel to grain must be set equal to the allowable stress in compression parallel.

3.3 Allowable Deflection

Deflection should not exceed that allowed by the applicable building code. Maximum deflections recommended are the following proportions of the span ℓ in inches.

3.3.1 Floor Beams

Live load only	$\ell/360$
Dead plus live load	$\ell/240$

3.3.2 Roof Beams

	Without Plaster Ceiling	With Plaster Ceiling
Live load only	$\ell/240$	$\ell/360$
Dead plus live load	$\ell/180$	$\ell/240$

3.3.3 FHA Requirements

Floor Beams.	Dead plus live load $\ell/360$ or 1/2"	whichever is less.
Roof Beams.	Dead plus live load $\ell/240$ or 3/4"	

3.3.4 Special Conditions

More severe limitations may be required for special conditions, such as the support of vibrating machinery, or beams over glass windows.*

3.4 Camber

3.4.1 Camber Optional

Camber may be provided opposite to the direction of anticipated deflection for purposes of appearance or utility. It will have no effect on strength or actual stiffness.

*For further discussion, see section on Camber in American Institute of Timber Construction TIMBER CONSTRUCTION MANUAL.

3.4.2 Recommended Camber

Where roof and floor beams are cambered, a recommended amount is 1.5 times the deflection due to dead load only. This will provide a nearly level beam under conditions of no live load after set has occurred.

3.4.3 Special Conditions

Additional camber may be introduced as desired to provide for drainage or appearance. Roof members must be designed to prevent ponding of water. This may be done either by cambering, or by providing slope or stiffness such that ponding will not occur.*

4. Lumber Flanges

4.1 General

4.1.1 Symmetrical Sections

Symmetrical cross sections are generally used in plywood beams for several practical reasons. These practical considerations usually outweigh the savings in material which theoretically can be achieved with unsymmetrical sections.

The design stresses for flanges are those for allowable stress in direct tension and direct compression. With symmetrical sections, the lower of these allowable stresses will limit the flange design. The following equations assume a symmetrical section.

4.1.2 Allowance for Surfacing

To allow for surfacing of flange laminations, they should be considered 1/8" smaller in both dimensions than their standard lumber sizes.

4.2 Bending Moment

4.2.1 Symmetrical Sections

In a symmetrical section allowable resisting moment may be calculated by the formula,

$$M = \frac{F_f I_n}{0.5h}$$

where

M = Resisting moment (in.-lb)

F_f = Controlling working stress parallel to the grain of the flange lumber (psi)

I_n = Net moment of inertia of continuous parallel-grain material in the section ($in.^4$)

h = Depth of beam (in.).

4.2.2 Unsymmetrical Sections

When the cross section is not symmetrical about its center, the resisting moment may be calculated as above, except that the distance from the neutral axis to each flange is used in place of the value 0.5h, and the moment of inertia is calculated with due regard for the location of the neutral axis. The location of the neutral axis is computed on the basis of the total cross section, without reduction for butt joints.

4.2.3 Net Moment of Inertia

4.2.3.1 Plywood Webs—Butt joints in plywood webs are usually spliced to transmit shear only, with a splice plate only as deep as the clear distance between flanges. If such butt joints in webs are staggered 24" or more, only one web need be disregarded in computing moment of inertia for bending stress. For joints closer than 24" the contribution of the webs should be neglected in computing I_n.

When webs are spliced full-depth so as to carry direct "flange" stresses, they may all be included in computing the moment of inertia with allowable stresses as in PLYWOOD DESIGN SPECIFICATION Table 5.6.1.2.

4.2.3.2 Flange Lumber—Butt joints in lumber flanges are required by the Fabrication Specification to be spaced at least 30 times the lamination thickness in adjoining (actually touching) laminations, and at least ten times the lamination thickness in non-adjoining laminations, if not otherwise stipulated in the design.

Therefore, in accordance with PDS Section 5.7, if butt-joint location is not otherwise stipulated by the designer, the net moment of inertia of flanges

*For further discussion, see section on Camber in American Institute of Timber Construction TIMBER CONSTRUCTION MANUAL.

which permit butt joints may be calculated by ignoring one lamination and ten percent of the two adjoining laminations.

Effects of other butt-joint arrangements are as given in PDS Section 5.7

4.2.4 Shims

4.2.4.1 Lumber Shims—If lumber shims are to be designed to take stress, they must conform with the requirements for a stress grade equivalent to that of the flange laminations.

4.2.4.2 Plywood Shims—The parallel-grain material in plywood shims may be figured for stress, at a stress level commensurate with its grade and modulus of elasticity.

5. Plywood Webs

5.1 General

Plywood webs are primarily stressed in shear through their thickness, although they may also carry bending moment, provided that individual panels are properly spliced to transmit both types of stresses. Also, sufficient contact area with the flanges must be provided to transmit the stresses between web and flange.

The number and thickness of the webs may be varied along the beam length in proportion to the shear requirements (Section 2.5) considering both shear through the panel thickness at the neutral axis, and rolling shear between flange and web. Where webs are dropped off, plywood or lumber shims may be glued to the flanges to maintain beam width as required for appearance or for gluing pressure.

When the depth of a beam is tapered, the net vertical component of the direct forces in the flanges should be considered in determining the net shear to be resisted by the webs and the flange-web joints. This vertical component may add to or subtract from the external shear. It is equal to M/ℓ_1, where M is the bending moment acting on the section, and ℓ_1 is the slope distance from the section to the intersection of the flange centerlines.

5.2 Horizontal Shear

The allowable horizontal shear on a section can be calculated by the following formula.

$$V = \frac{F_v I_t \Sigma t}{Q}$$

where

V = Allowable total shear on the section (lb)

F_v = Allowable plywood shear stress through the panel thickness (psi). See PDS Section 3.14

I_t = Total moment of inertia about the neutral axis of all parallel-grain material, regardless of any butt joints ($in.^4$)

Σt = Total thickness of all webs at the section (in.)

Q = Statical moment about the neutral axis of all parallel-grain material, regardless of any butt joints, lying above (or below) the neutral axis ($in.^3$).

5.3 Splices

Effectiveness of spliced joints in resisting flexure and shear is given in PDS Section 5.6.

5.4 Holes in Webs

Holes in plywood webs should be avoided if possible. If they are required, they should be located in areas of low shear, with proper consideration for the shear capacity of the remaining section. It is good practice to avoid sharp corners, and to use a plywood "doubler" in the area of the hole.

6. Flange-Web Joints

Joints between flanges and webs at any section must be designed to resist the shear acting on that section. Stresses are carried wholly by glue, not by any combination of glue with mechanical fasteners.

6.1 Type A, B, and I Sections

The allowable flange-web shear on a glued, symmetrical two-web section (Type A or B beam) in which only one face of each web contacts the flange, or on an I section, may be calculated by the following formula.

$$V = \frac{2F_s dI_t}{Q_{fl}}$$

where

V = Allowable total shear on the section(lb)

F_s = Allowable plywood rolling shear stress (psi) as given in PDS Section 3.14, with the 50% reduction for shear concentration

d = Flange depth (in.)

I_t = Total moment of inertia about the neutral axis of all parallel-grain material, regardless of any butt joints ($in.^4$)

Q_{fl} = Statical moment about the neutral axis of all parallel-grain material in the upper (or lower) flanges, regardless of any butt joints ($in.^3$).

6.2 Beams with Multiple Webs (Type C Sections)

Maximum flange-web shear on beams with more than two webs may be computed using the assumption that the horizontal shear stress is equal in all webs. For calculations, flanges are then broken down into areas "tributary" to each web, and flange-web shear figured separately for each contact surface. Tributary areas are generally assigned such that the first moment (Q) of the area tributary to each web is proportional to the thickness of the web.

For a type C1 beam in which the center web is less than twice the thickness of an outer web, the maximum stress occurs on the outside web, and is given by the following formula.

$$V = \frac{F_s dI_t}{Q_{fl}} \frac{\Sigma t}{t}$$

where

Σt = Sum of all web thicknesses at the section (in.)

t = Thickness of the outer web (in.).

Other notation as in Section 6.1.

7. Stiffeners

7.1 Bearing Stiffeners

Lumber bearing stiffeners are required over reactions and where other heavy concentrated loads occur, to distribute such loads into the beam. They should fit accurately against the flanges, and the webs should be securely attached to them.

7.1.1 Bearing Stiffeners at Ends of Beams

Bearing stiffeners at ends of beams should be the same width as the lumber flange at that section. Their dimension parallel to the beam span should not be less than that given by the following two considerations.

7.1.1.1 Compressive Strength—The thickness of stiffener must be at least equal to x in the following equation.

$$x = \frac{P}{F_{c\perp} b}$$

where

x = Thickness (in.) of stiffener (parallel to beam span)

P = Concentrated load or reaction (lb)

$F_{c\perp}$ = Allowable stress in compression perpendicular to grain for the *flange* lumber (psi)

b = Flange width (in.).

7.1.1.2 Rolling Shear—For Type A, B, and I sections, the thickness of stiffeners must be at least equal to x in the following equation. For Type C beams, or others with more than two webs, the rolling shear stress will be less likely to govern.

$$x = \frac{P}{2hF_s}$$

where

x = Thickness (in.) of stiffener (parallel to beam span)

h = Depth of beam (in.)

F_s = Allowable plywood rolling shear stress (psi) as given in PDS Section 3.14 with the 50% reduction for shear concentration.

7.1.2 Bearing Stiffeners Not at Ends of Beam

For bearing stiffeners not at ends of beam, factors given in NDS Section 400-H may be applied to $F_{c\perp}$.

7.2 Intermediate Stiffeners

7.2.1 Function

Intermediate stiffeners are required to stabilize the flanges, to space them accurately during fabrication, to reinforce the webs in shear and prevent their buckling, and to serve as backing for gluing of web splice plates where prespliced or scarfed webs are not used. Such stiffeners are usually of 2-in. dimension lumber, and are equal in width to the lumber flange between webs, allowing for splice plates, if any.

7.2.2 Spacing

Intermediate stiffeners spaced 48" or less on centers will develop all, or nearly all, the shear strength of a beam of normal propertions, as evidenced by American Plywood Association tests.

8. Deflection

The deflection of plywood beams may be taken as the sum of the calculated deflections due to bending and to shear. It should not exceed the values given in Section 3.

The bending deflection may be calculated by conventional engineering formulas, with due regard to loading conditions and fixity of supports. Deflection due to several simultaneously applied loads may be calculated separately and added.

Total deflection may then be obtained by one of the following methods. If the Approximate Method indicates that total deflection governs the design, or nearly does, a check should be made by the Refined Method.

8.1 Approximate Method

The total deflection of simply supported, uniformly loaded plywood beams may be approximated by multiplying the bending deflection by a factor depending on the span-depth ratio, to allow for shear deflection. The bending deflection is found by conventional formulas, using the elastic modulus of the flange lumber tabulated in the NDS, and the moment of inertia of all parallel-grain material in the section, regardless of any butt joints.

The following shear-deflection factors may then be applied to the bending deflection, with interpolation permitted.

Span/Depth	Factor
10	1.5
15	1.2
20	1.0

8.2 Refined Method

The total deflection may be calculated by separately computing the bending deflection and shear deflection, and adding the two.

8.2.1 Bending Deflection

In calculating the bending deflection, the elastic modulus of the flange lumber may be increased by 10% over the values tabluated in the NDS. (See PDS Section 5.5.6.) The moment of inertia used

for computing the bending deflection is I_t, the moment of inertia of the parallel grain material in the section, regardless of butt joints. (Note that the moment of inertia used for computing *shear* deflection is that of *all* material in the section, including cross plies in the webs, regardless of any butt joints.)

8.2.2 Shear Deflection

The shear deflection may be calculated using the formula,

$$\Delta_s = \frac{P\ell\, Kh^2 C}{GI_g}$$

where

Δ_s = Shear deflection (in.)

P = Total load on beam (lb)

ℓ = Span length (in.)

K = A factor determined by the beam cross section, and shown in Figure 8.2.2, page 9

h = Depth of beam (in.)

C = A coefficient depending on the manner of loading, also shown in Figure 8.2.2, page 9

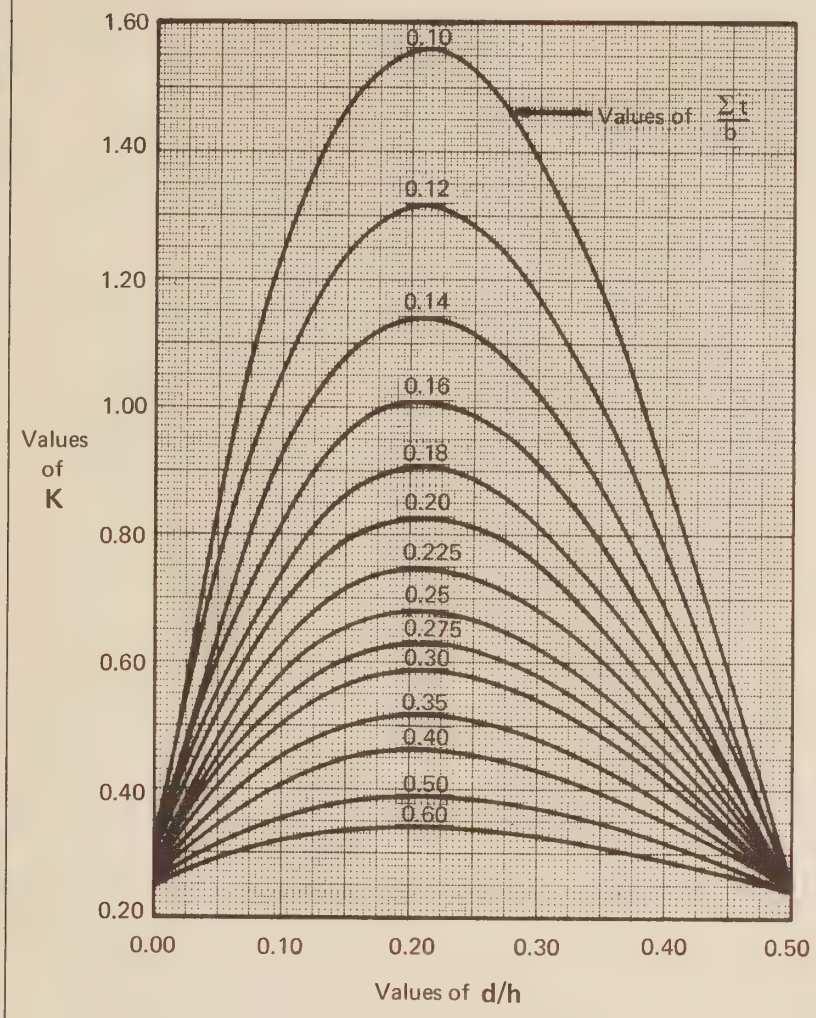
G = Shearing modulus of the webs (psi). (From tests, G may be taken as 1/20 E for panels with exterior glue. Reduce 9% for panels with interior glue. Reduce an additional 16% for beams where equilibrium moisture content in service will be 16% or higher. For example, G for Structural I plywood in a dry location is 90,000 psi.)

I_g = Gross moment of inertia (in.^{4}) of all material in the section. (For calculating I_g, use "Effective Thickness for Shear" from Columns 3 or 4 of Section 2.10 of PLYWOOD DESIGN SPECIFICATION. For instance, figure thickness of 1/2" Structural I plywood as 0.574".)

9. Lateral Stability

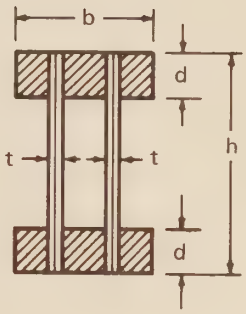
Deep, narrow beams, particularly those used on long spans, may require definite lateral restraint to prevent buckling. The ratio of the total moment of inertia of all parallel-grain material about the horizontal neutral axis to that about the vertical axis will determine the minimum lateral support required, as given in the following table.

I_x/I_y	Provision for Lateral Bracing
Up to 5	None required.
5 to 10	Ends held in position at bottom flanges at supports.
10 to 20	Beams held in line at ends (both top and bottom flanges restrained from horizontal movement in planes perpendicular to beam axis).
20 to 30	One edge (either top or bottom) held in line.
30 to 40	Beam restrained by bridging or other bracing at intervals of not more than 8 ft.
More than 40	Compression flanges fully restrained and forced to deflect in a vertical plane, as with a well-fastened joist and sheathing, or stressed-skin panel system.

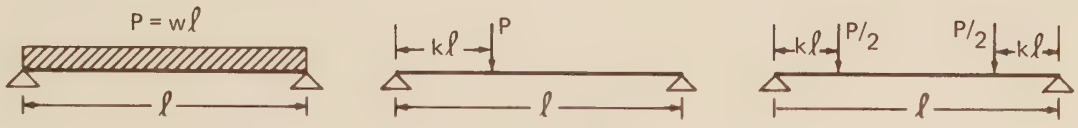


SECTION CONSTANT

Sections symmetrical about horizontal and vertical axes



$$K = \frac{1}{4}\left[1 + \frac{12d^3 - 18hd^2 + 6h^2d}{h^3}\left(\frac{1}{\frac{\Sigma t}{b}} - 1\right)\right]$$



Uniform Load
C = 0.05

Concentrated Load
C = 0.4k (I-k)

Equal Symmetrical Concentrated Loads
C = 0.2k

LOAD COEFFICIENTS

FIGURE 8.2.2 Section Constant and Load Coefficients for Shear Deflection Equation

Notes:

Notes:

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